Space Weather Technical Forecast

Issued on Friday, 15 December 2023 at 01:29 Local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: High activity with further M-flares likely, and chance of X-flares (R1-R3). G1 Minor Storms possible from CME arrival day 2 (16 Dec). Further analysis required on X-flare CME, but perhaps a chance of G1-G2 day 3 (17 Dec).

Analysis of Space Weather Activity over past 24 hours

Solar Activity: High with peak flare X2.8 from AR3514 in the northwest disc, peaking 14/1702 UTC. This was the largest flare of SC25 so far, and the largest since Sep 2017. Two M-flare were also observed from this region including an M5.8 peaking 14/0744 UTC and an M2.3 peaking 14/1348 UTC. This is a complex and moderately sized region approaching the northwest limb, which saw ongoing growth and development through the last 48 hours. This resulted in a broad penumbra, consisting of multiple umbrae of different polarities and subsequently of a beat-gamma-delta configuration. Since the X-flare, development of the region has continued and further flares are possible. This is one of seven other active regions on the disc, however the other regions are largely smaller and simpler, with no significant growth observed.

Two CMEs were observed in the last 24 hours with potential Earth-directed components. The first was due to a filament eruption across the north of the Solar disc, starting 14/1109 UTC, and the second was from the X2.8 flare. The first has yet to be analysed due to a lack of imagery, however sufficient STEREO A coronagraph images have enabled a preliminary assessment of the X2.8 flare CME. This is mainly passing ahead of Earth, but with a potential arrival early on day 3 (17 Dec). Any other CMEs in the last 24 hours have been assessed as not having earth-directed components

Solar Wind / Geomagnetic Activity: Solar winds were indicative of the tail end of a passing weak CME, which had arrived late on 13 Dec. Speeds, as measured by ACE at L1, persisted at background, near 350 km/s, with density largely below average. The interplanetary magnetic field (IMF), Bt, was initially Moderate at 15nT, but eased to be Weak around 4-6nT. The north-south component, Bz, was generally negative (southward) initially Moderate at -14nT, but eased to be Weak at -4nT. Phi angle remained positive (away from the Sun). Geomagnetic activity was initially Unsettled to Active (Kp 3-4), but eased to be Quiet from 14/1500 UTC (Kp1-2).

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux was at Background levels until 14/1900 UTC, then rose to be slightly above background peaking 0.89pfu at 15/0000 UTC, with an increasing trend. This was in response to the X2.8 flare of AR3514. GOES16 high energy (greater than 2MeV) electron flux was also background. The 24-hour fluence was below the Active threshold (1e8 integrated pfu). The observation at 15/0000UTC was 1.19e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Moderate to High activity expected with the ongoing likelihood of M-class (R1-R2) flares and a chance of further isolated X-class (R3) flares from AR3514. This risk recedes later day 3 and through day 4 (17-18 Dec) as the region moves further around the far-side.

Solar Wind / Geomagnetic Activity: There are two Earth-directed CMEs arrivals expected. The

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first from 13 Dec filament eruption near AR3514, early on day 2 (16 Dec), and the second from the X2.8 flare on 14 Dec. This second one still requires further analysis, however a preliminary arrival time has been estimated for early day 3 (17 Dec). Otherwise CH79/+ may bring a weak enhancement on day 1 (15 Dec) with solar winds perhaps rising to around 450 km/s, while CH82/+ has the potential to enhance winds on day 4 (18 Dec), although this is very low confidence. Overall, geomagnetic activity is forecast to be Quiet at first, rising to Unsettled to Active with coronal hole enhancements day 1 and day 4 (15 and 18 Dec), with a slight chance of G1 Minor Storms. The CME arrival early on day 2 (16 Dec) brings a chance of a spell of Active to G1 Minor Storm intervals. The CME arrival on day 3 (17 Dec) is less certain, but could bring G1-G2 Minor to Moderate storms.

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is currently on a slow rising trend, and may approach the S1 Minor Radiation Storm threshold day 1, with a slight chance of exceeding this. There is also a chance that further significant flares from AR3514 will bring a risk of proton flux rising above the S1 threshold. High energy electron flux, as observed by GOES16, is currently at background. Background flux is likely to persist until after any CME influence recedes, either later day 3 or day 4 (17-18 Dec). Flux may then rise with a chance of reaching Moderate, perhaps High by the end of day 4. The associated 24 hr electron fluence is expected to remain below the Active threshold.

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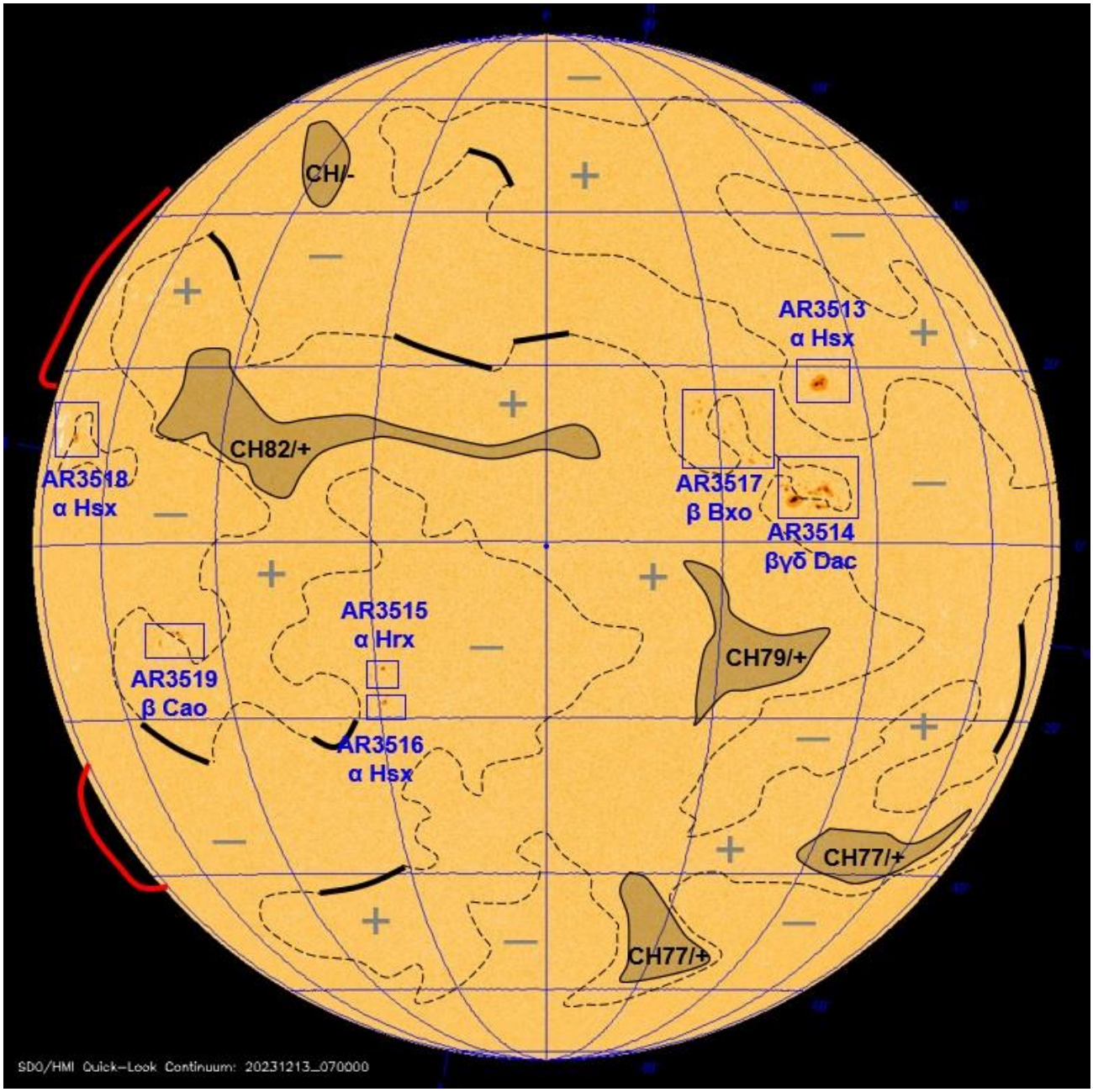
Figure 1. Solar Analysis Valid 14/2000 UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

There are three main Earth-directed CMEs.

The X2.8 flare from AR3514 at 14/1702 UTC produced a moderately fast CME which has had a preliminary assessment as having an Earth-directed component, likely arriving early on 17 Dec. However SOHO imagery is currently unavailable for this event, so this analysis used only Stereo A coronagraph images. This leads to low confidence in this analysis, and further updates are possible.

The second CME is from a filament eruption near AR3514 on 13 Dec and is expected to arrive early day 2 (16 Dec) however this low confidence. Any impact is also likely to be limited due to the faint nature of the CME.

A further weak CME was observed early on 14 Dec. This was from a filament eruption off the north disc starting around 14/1109 UTC. This has not been assessed due to a lack of imagery, but would likely be cannibalised by any arrival from the X-flare CME.

Otherwise enhancement is possible from the arrival of any fast wind from CH79/+ on day 1 (15 Dec) This is a very small feature in the southwestern quadrant, having recently reduced in size in SDO imagery. However, as a larger feature when in centre disc, the associated fast wind still has a chance to give a weak enhancement. This is later than originally forecast, with expected speed of around 450 km/. Confidence is low however, as this feature is not present in enlil, which is currently overestimating the influence of a southern coronal hole CH77/+.

CH82/+ also has a westwards extension that may then enhance the solar wind day 4 (18 Dec), however this very low confidence.

Overall, the geomagnetic forecast is low confidence, with Quiet conditions at first, likely rising to give a spell of Unsettled to Active with any enhancement from CH79/+. The first CME arrival is likely to give a spell of Active to G1 Minor Storms on day 2 (16 Dec). The second CME arrival is very low confidence at this stage, however given the current preliminary analysis (which is likely to be updated) there is a chance of G1-G2 Minor to Moderate storms early day 3 (17 Dec). A return to mainly Quiet is likely into day 4 (18 Dec), perhaps increasing again to Unsettled to active with any fast wind enhancement from CH82/+.

Geo-Magnetic Storm	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability (Exceedance)			(%)	(%)	(%)	(%)
Minor or Moderate	G1 to G2	No	10	40	40	10
Strong	G3	No	1	15	15	1
Severe	G4	No	1	2	2	1
Extreme	G5	No	1	1	1	1

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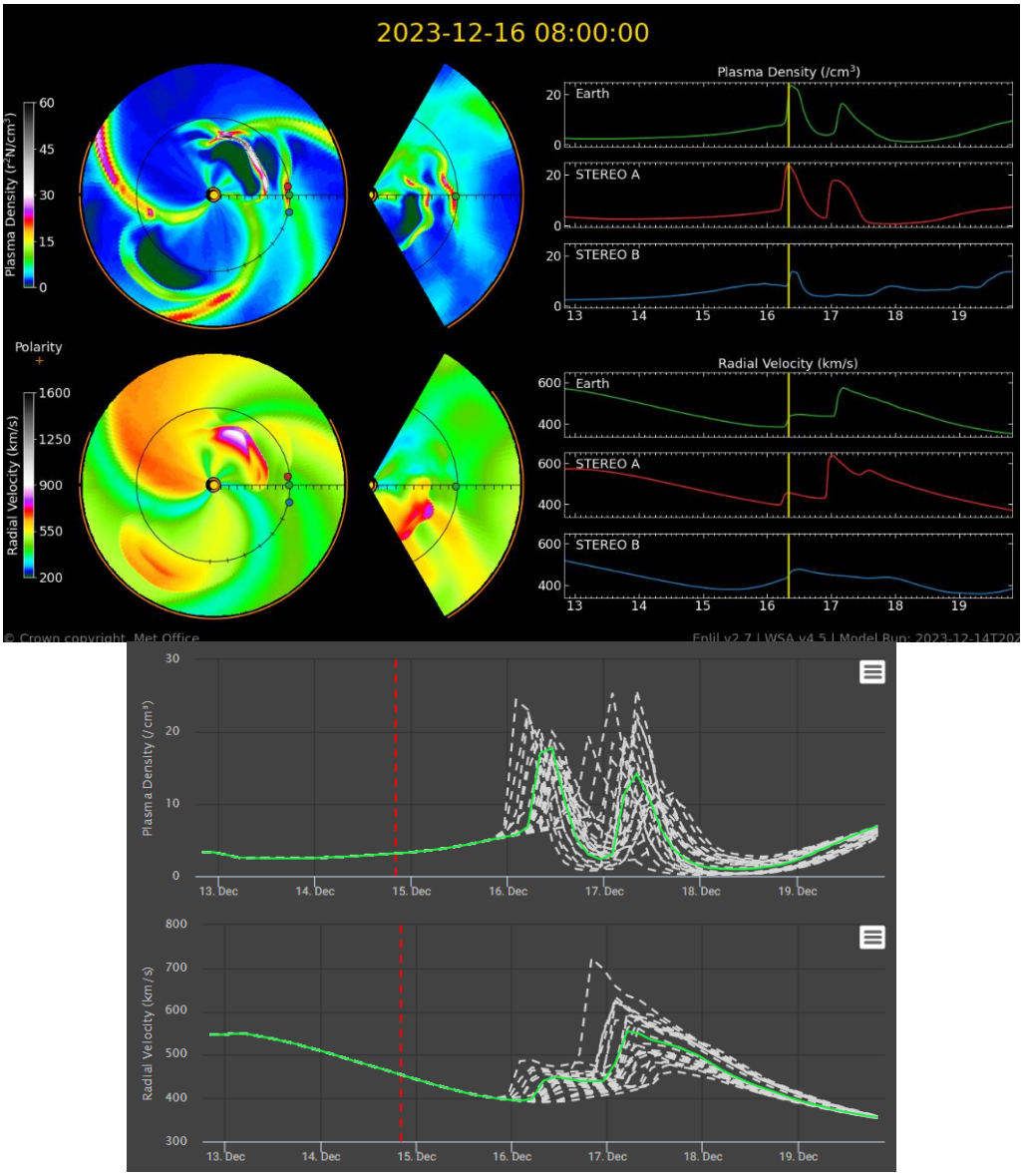
Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
13/0555	Partial	Filament nr AR3514	NW	530	Early 16 Dec	Low confidence
14/2112	Full	X2.8	NW	974	Early 17 Dec	Preliminary fit only. Likely to be adjusted.

Figure 2: Enlil and ensemble.



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Radio Blackouts - X-Ray Flares:

Moderate to High activity is forecast, with the ongoing likelihood of M-class (R1-R2) flares and a chance of further X-class (R3) flares from AR3514.

This region is a complex and moderately sized sunspot on the northwest disc. Much of the sunspot is connected to create one large penumbral region, with many component umbrae, although there are some indications of the development and separation of main trailer and leader spots. SDO imagery, such as aia-171 continue to show a complex pattern of looping, although some of this is likely the recovery after the recent X2.8 flare event. Given the position of the region, this will become more difficult to analyse through the period. Furthermore, while near limb far-sided flares can be visible Earth-side, the potential for strong flares will gradually decline through days 3 and 4 (17-18 Dec) as this region moves over the northwest limb and further onto the far-side.

There are a total of seven sunspot regions on the disc, however the other regions remain small and simpler with no notable growth.

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	Yes	70	70	60	50
Very Active	R3 to R5 X Class	Yes	30	30	20	5

Figure 3: GOES-16/18 X-ray Flux and SDO-aia 94 showing X-flare

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Solar Radiation Storms - (High Energy Protons):

The high energy (greater than 10MeV) proton flux observed by GOES16 has risen above background after the X2.8 flare from AR3514, but currently remain below the S1 Minor Radiation Storm level. This flux will have the potential to continue rising early day 1 (15 Dec), but will like peak below the S1 level with only a slight chance of exceeding it. However, given its location on the northwest disc further significant flares from AR3514 will bring a chance of reaching this level through the period. While the region will rotate over the limb during day 3 (17 Dec), any far-side flares day 4 (18 Dec) will continue to give a risk of high energy protons.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	≥ S1	No	30	25	25	20
Very Active	≥ S3 *	No	5	5	5	5
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

Figure 4a: GOES-16 Proton Flux (>10MeV, >50MeV, >100MeV)

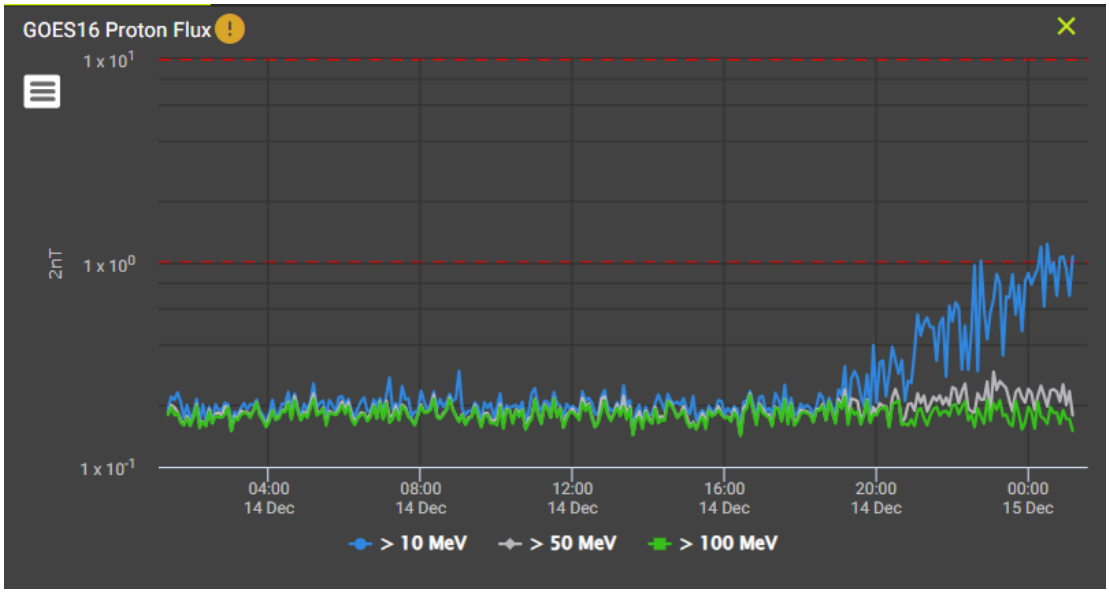

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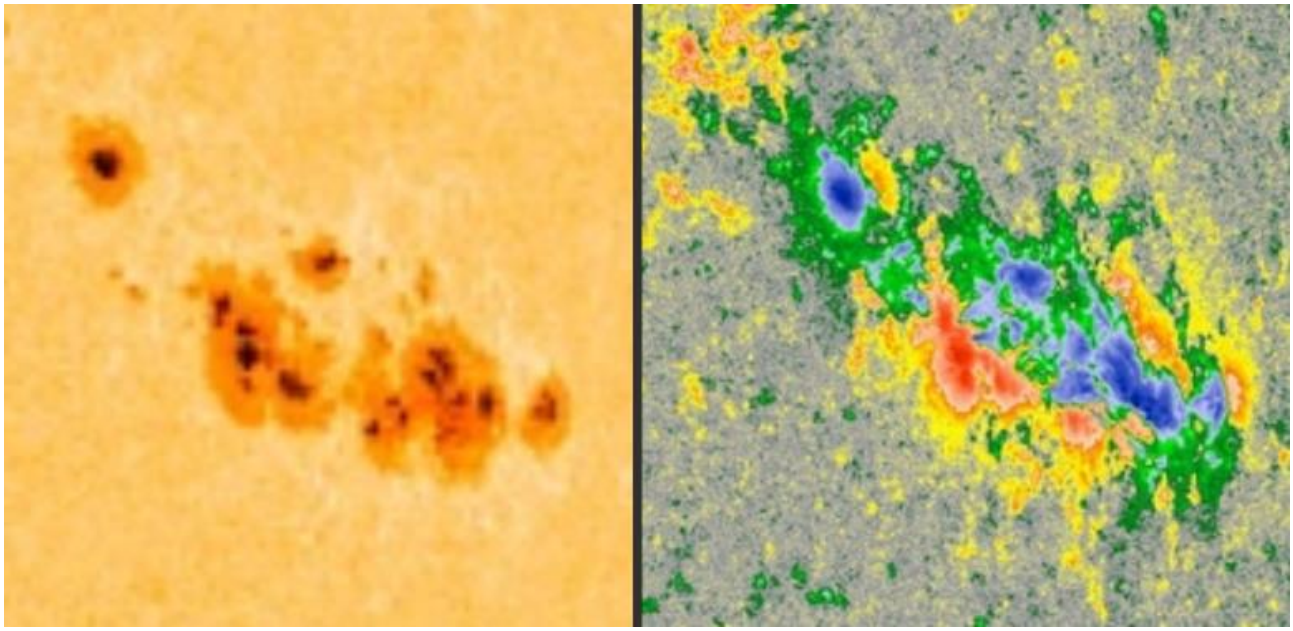
Figure 4b: SDO Intensitygram and Magnetogram of AR3145



High Energy Electrons Event (≥ 2MeV):

High energy electron flux, as observed by GOES16, is currently at background. The timing and strength of solar wind enhancement from CH79/+ is low confidence, but is currently expected to be relatively weak, occurring day 1 (15 Dec). This will limit the extent of any increased flux in the Van Allen Belts. Furthermore, the arrival of two CMEs on days 2-3 (16-17 Dec) are likely to decrease these values further, with the Van Allen belts compressing inward. As solar pressure eases, with any CME influence declining, the observed flux may respond by increasing to Moderate, with a chance of peaking at High by day 4 (18 Dec).

The associated 24-hour fluence is expected to remain below the Active threshold, as indicated by REFM, although this model doesn't take account of either the fast wind arrival or CME impacts. There is a slight chance that CME enhancements result in Active fluence by the end of day 4 (18 Dec).

GEO Electron Environment	Level ($cm^{-2}\ sr^{-1}\ day^{-1}$)	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability (Exceedance)			(%)	(%)	(%)	(%)
Active	≥ 2 MeV ≥ $1x10^8$	No	1	1	5	20
Very Active	≥ 2 MeV ≥ $1x10^9$	No	1	1	1	1

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